What Does the Wave Function Represent and How Should We Interpret it?

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Abstract The wave function has been with us for one hundred years and constitutes the core of quantum mechanics (QM). It is disconcerting that we still don't know the nature of the matter waves that the equation represents. Photon waves have some commonality with matter waves and at least we know their constituents: kinetic energy, momentum, and electromagnetic (EM) oscillations. In fact, photon waves exhibit most of the puzzling features of QM including probability and collapse. Piecing together the clues the photon gives us is the best way to make progress on the wave function and the major issues confronting QM: duality, collapse, probability, constant velocity, even nonlocality and the measurement problem.

Keywords photon; wave-particle duality; wave function; nonlocality; measurement problem; Schrödinger's cat

I Issues with photon energy and its delivery

Energy: The photon has momentum the transfer of which in time to something movable (e.g., electron, atom) is work done that we choose to call energy. We arrive at energy values either by measuring momentum change over time and space or we calculate energy via other measurements, e.g., from momentum times velocity ($\frac{1}{2}mv^2$) or from radiation frequency. As formulas (and dimensions) for energy reveal, we always measure energy indirectly. Our definition for it ("the ability to do work") is circular. Its exact nature remains an unknown in terms of its presence in a dimension (if it has one) or its status (quantity or entity). As Richard Feynman writes, "It is important to realize that …we have no knowledge of what energy *is* [1, 4-1]."

a. **Energy, including photon energy, is not accessible to us. We either calculate it or we measure it via momentum change. Our knowledge of it, and of momentum, is limited to its quantitative value.**

b. **Kinetic energy is regarded as a quantity (scalar) for classical physics, quantum mechanics (QM) and quantum field theory (QFT).**

Energy delivery: Another issue has to do with the transmission of photon kinetic energy. Since the latter as a quantity lacks a defined, physical presence in space, something else – particle or field – must facilitate photon energy's transmission from emission to absorption.

Classical physics held that particles carry kinetic energy in space. QM agreed with that but allowed for particles that were massless (the photon) or even virtual to carry both kinetic energy and force over space.

QFT proposed that all particles, including the photon, are actually energy excitations in a continuous-yet-quantized field. Although QFT has its fields residing in space, their exact nature there – physical or mathematical or some combination – has never been clearly settled.

c. All our physics theories – classical, QM and QFT – agree that photon energy transmission requires a space object (either particle or field) as carrier or enabler.

Both QM and QFT are more successful at describing the hydrogen atom's electron than the massless photon traversing space. If the nature of photon energy is problematic and its delivery more so, perhaps looking at photon waves can help.

II Photon waves in space

Several things about photon waves are obvious. They are objectively real in space since we can manipulate them with mirrors and slits. They are immaterial since radiation is without rest mass. These waves are also probabilistic.

Photon waves travel all available paths but do so with unequal intensity. Paths of high intensity feature higher probability of photon reception. A low intensity wave path for an individual photon may feature a reception event, but the probability of this happening is low.

Wave path intensity is not a function of many photons "on that path." Rather, each photon allocates intensities for all available paths and successive identical (coherent) photons repeat that pattern. This allows identical photons to separately navigate a double slit and still create – in aggregate, via probability – the diffraction pattern that wave optics can predict by assuming a single wave gets diffracted. The relation of a photon's wave path intensity to reception probability for that path is real; its exact nature will be covered presently.

a. Photon reception is probabilistic and photon wave path intensity correlates with the likelihood of photon reception on that path. But photon reception is random for the instance.

The inflight waves of a single photon may bifurcate in a beam splitter yet one path, or the other, receives the undiminished photon energy. This indicates that divisible, probabilistic, inflight photon waves have no energy to divide. They appear to acquire or invoke energy only when they interact with matter as in reception or Compton scattering. Are they probability waves that only activate at reception? How can that work?

III Photon waves and momentum

A single photon's inflight waves may not carry kinetic energy that can be bifurcated, but they do have momentum which must have a space presence since it is a vector. We can calculate inflight photon momentum and even possibly measure it (mirror recoil).

Momentum currently is a contradictory classical concept we still embrace without reflection; a quantity that doesn't require space but is nevertheless a vector there. The momentum you have been taught dates from Descartes and Newton; because it works in equations it has never been reexamined.

Kinetic energy and momentum are always found together. As the massless photon proves, momentum is a function of, and *dependent* upon, kinetic energy and not upon rest mass. In fact, photon momentum is a direct expression of the photon's kinetic energy, $p = E/c = hf/c$. This makes photon momentum also dependent upon wavelength, $p = h/\lambda$. Momentum of any object – massive or massless – features advancement in space. And since the photon is immaterial, so is its momentum.

a. Photon momentum, a function of photon wavelength, is a space-advancing, immaterial dependency of photon kinetic energy, p = E/c.

Because photon waves expand in space, these waves constitute an immaterial wavefront. Photon momentum wave cycles are also synched with photon electromagnetic (EM) oscillations. This gives photon waves two physically-real constituents that are immaterial while tracing out paths of objective reception likelihood in space (II.a above).[1]

b. Photon waves comprise two immaterial, but objectively real (detectable) constituents in space, momentum cycles ($p = h/\lambda$) and EM cycles advancing in synch at the speed of light. These waves trace out paths of objective reception likelihood. All this is basic physics.

c. As a dependency of photon kinetic energy, the photon momentum wavefront has, like any momentum, the capacity – the potential – of doing work via a reception event.

d. Everyone assumes that the photon delivers a quantity of kinetic energy leading to momentum change for the receptor. Actually, we only detect/measure momentum change (our work), not energy itself. We have no evidence that kinetic energy is accessible to us (I.a).

e. The photon's probabilistic reception event collapses its momentum wavefront and constitutes a change of state (reception) for photon kinetic energy.

We then have a dependency which: 1) is immaterial yet present in space; 2) traces out only likely change-of-state paths for that upon which it depends; and 3) can initiate that change of state and then disappear. Such an immaterial wavefront sounds very much like a latency; something not itself actual, yet embodying potential change.

f. Is it possible that photon momentum is an objective, space-advancing potentiality for photon energy's change of state?

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[1] QFT requires anything immaterial to have a quasi-existence in space as a field or an "object." Hence it posits an excitation as a field *state* (an object) with momentum as its property. Particle physics becomes object physics when there is no rest mass involved.

IV Momentum and potentiality

Numerous prominent physicists have put forth the concept of potentiality over the centuries, from Aristotle and his *potentia* to Heisenberg, Margenau, Shimony and many, many others [2, p.8-9]. Einstein and his ghost waves may be added to the list [3, p.2-3]. Those tempted to dismiss potentiality out of hand may substitute Shimony's "objective probability [4, p.47]" in its place.

That which is potential cannot be material nor even fully realized/actual in a dimension, yet it must be present there to be objective and hence part of physics. Being present in a dimension, say space, means we should be able to influence or deflect its passage or location. But devoid of any rest mass or energy, a potentiality won't itself register on our instruments, only what it invokes will.

Without being fully real itself, a potentiality must still be related to – i.e., sourced from, and dependent upon – some object that is fully real and whose change we can detect. In addition, this fully-real object must be predisposed to undergo a change of state that is probabilistic, not deterministic.

This fully-real object susceptible to a probabilistic change of state over space (reception) is photon oscillatory kinetic energy. Its immaterial dependency acting as a potential agent of likely change over space is a photon momentum wavefront tracing out paths of varying reception probability.

a. **Photon momentum is potential because it is an immaterial, waveform expression (dependency) of photon kinetic energy; it constitutes objective potentiality/latency advancing on its own in space; it has no carrier.**[2]

b. **The relative intensity of (potential) photon momentum on a wave path determines objective probability for a photon's kinetic energy event (reception) on that path (II.a).**

c. **With photon momentum being potential (latent), the accompanying EM waves must also be potential to avoid a mismatch.**

d. **Potential EM waves become "kinetic" when interacting with a charge (Lorentz force law). Photon potential momentum waves become "kinetic" when interacting with a rest mass (momentum reception as force).**

We are accustomed to classical momentum as a quantity that may be partitioned via particle interactions, but never rarefies. But the wavefront of a single photon will expand indefinitely and its momentum must therefore rarefy in space without limit. It is the potential/latent nature of photon momentum – and of EM oscillation – that makes rarefication possible. Photon momentum rarefication attenuates reception probability over space; but rarefying something latent has no effect upon that which sustains it, namely quantized photon kinetic energy.[3] It is only when potential momentum triggers a

[2] That something immaterial yet actually present in space – like momentum – can advance/occur without a carrier object (a particle), or without a hosting field, is contrary to current physics. Hence the need to make the photon into a particle or a field ripple carrying a payload. The field or particle must exist, not occur, in space, although virtual existence is sufficient. We grow up with existing things in space; that is how we frame radiation and the microworld.

[3] Cell towers emit latent waves that initiate reception events on your phone of quantized energy. But separation from the tower rarefies these likelihood-of-reception waves reducing your chances of receiving intact energy quanta. Distance attenuates wave latency/possibility; it does not diminish energy quanta as received. See Sec. VII, VIII.

reception event that momentum converts from potential to kinetic as a work event with a now-defined space location and vector orientation.

V Understanding potentiality and momentum

As noted (Sec. II), the random reception points of identical, slit-diffracted photons collectively constitute a waveform interference pattern. It is latency that permits this mystifying, dualistic behavior whereby discrete and random aggregates to the collective continuous.

A photon has no rest mass; its only space presence is a self-advancing, momentum (and EM) wavefront. Because it is an immaterial dependency that photon kinetic energy sustains in space, this momentum is potential making it a latency: i.e., a wavefront of reception-event possibilities for all available paths. When this wavefront reaches the screen, the momentum is forced to convert from potential to "kinetic" and randomly initiate a particular space-path-event, reception.

At arrival, a photon's momentum intensity weighting over the screen varies from very weak to very strong. Because latencies only encapsulate possibilities, the reception event location for an individual photon is totally random on the screen. But these weighted possibilities are objective as a momentum wavefront of varying intensity. While individual photons may pass up a strong latency/momentum path in favor of a weaker path for initiating reception, this contravenes objective probability and can't happen very often. For the aggregate, photon reception distribution will reflect the momentum/latency path weighting that every (coherent) photon acquires via slit diffraction.

To summarize:

a. **Photon kinetic energy is oscillatory (E = *hf*) and subject to probabilistic change of state.**
b. **Energy oscillation gives dependent, self-advancing photon momentum the waveform.**
c. **Dependent, immaterial photon momentum waves are spatially present but latent.**
d. **Momentum path intensity correlates with reception likelihood (change-of-state latency).**
e. **Photons encode wave behavior and probability via the latency of potential waveform momentum.**

Nature is ingenious; She also embraces latency.

As noted in Sec. IX below, electrons[4] also have potential momentum as an objective, probabilistic latency; it is what the wave function models.

f. **Self-advancing photon momentum has the capacity to initiate energy transfer (work), plus an objective, path-differentiated likelihood to do just that. There is no need to posit (I.c) a space object – either particle or field – as a carrier or enabler for photon kinetic energy transmission. At creation, photon kinetic energy arranges for its own transmission.**

g. **Photon momentum is the objective, space-present potentiality so many great minds have sought. When not ignored, it has been totally misinterpreted.**

[4] Electrons differ from photons in being truly dualistic: discrete rest mass plus continuous momentum waves. We misrepresent the massless photon as dualistic by conflating point reception with particle impact. See Sec. IX.

QM, QFT and the Standard Model all retain the classical physics concept of kinetic energy as a quantity delivered by a space-traversing object: particle, virtual particle or field ripple. The ability (and potentiality) of the self-advancing, immaterial momentum of the massless photon to do work is overlooked and probably always will be. Humans cannot let go of space traversal requiring some type of discrete object-carrier following a trajectory. That is built into our experience and we never question it. We insist on applying that model to the massless photon.

Classical physics/mechanics is *deterministic* and focuses on *existing* (rest mass) objects (particles) in space. QM and QFT (without design, incrementally) made two fundamental changes to this view to facilitate mechanics for radiation. First, probabilistic superposition replaced determinism for quantum objects and for the equations that described them. And second, objects could "exist" in space minus rest mass and trajectory: photons, virtual photons, fields, field excitations and even "quantum systems."

As the photon proves, momentum is a (dependent) product of kinetic energy, not of moving rest mass. Momentum of any object is only measurable when it converts – partially or fully – to be actual (kinetic). Hence no experiment we can perform will give us proof positive of the latent nature of unterminated, immaterial momentum traversing space. If we lack such proof, the same can be said for the space presence of the harmonic oscillators of the Dirac field. In both cases we must divine the presence, or the nature, of these things indirectly from the clues available to us. And we must justify our theory – of photon momentum latency, of a field of harmonic oscillators – by the number and the importance of the known issues they resolve, not by computational precision.[5]

Freeing radiation from a space-traversing object with superposed states makes many phenomena much easier to understand without invoking ad hoc explanans. An example illustrates this.

VI The three-polarizer paradox

If you have two polarizers with the first set at vertical and the second at horizontal, all polarized light exiting the vertical polarizer gets blocked by the horizontal polarizer. But if a third polarizer set at a 45° angle is inserted between the vertical and horizontal polarizers, then 12.5% of the photons entering the vertical polarizer now get through the horizontal polarizer.

Most explanations of this paradox [5] assume that a photon as a particle with superposed polarization states traverses the polarizers. Early on Dirac cited a "special kind of relationship" that allows "… any state of polarization to be resolved into, or expressed as, a superposition of, any two mutually perpendicular states of polarization [6, Sec.2]."

Superposition of states here is a hidden variable argument applied to an unknown object, namely "the photon." And different orientations of measurement (of perpendicularity) give different states of polarization which is reminiscent of Bohr's position that "reality depends upon how you measure it." In general, all arguments for this paradox are flawed by the assumption that an actual photon object (a particle or similar) possessing multiple polarization "states" traverses the polarizing filters.

[5] Theories can be proven wrong; they can't be proven right. Producing a computational result that agrees with experiment – to whatever precision – does not prove the underlying theory is correct. This is easily forgotten; our current theory of momentum excels for computational purposes.

Photon momentum and synched EM cycles are both the products of the same kinetic energy: the acceleration of an electron. And both are self-advancing, dependent latencies whose respective waves constitute objective possibilities. For photon momentum waves, possibilities are the range of likely reception locations; for photon EM waves they are the range of likely polarization orientations.

When a photon enters a vertical polarizer, its potential EM waves self-interfere which sets latent polarization possibilities to favor vertical orientation. But latencies in the quantum world are never sharply defined; these waves as latencies retain some possibilities for waves at off-vertical angles.

Of course, any EM horizontal waves are blocked by the vertical polarizer and may, or may not, initiate photon reception. Those initiating reception on any of the three polarizers diminish the number of photons traversing the apparatus.

For those waves reaching the polarizer set at 45°, a second interference occurs (something physical!). This resets all latent polarized orientations to favor 45° orientation. But once again, latent orientations cannot all be at one angle; some waveform possibilities emerge for horizontal, or near horizontal, orientation. This enables a subset of waves – and a subset of reception possibilities – to pass the third (horizontal) polarizer.

There is no need for a "special relationship," or for bra-ket (particle) notation, or for hidden variable superposition. Instead, just recognition of an objective, space-traversing waveform latency that encompasses polarization orientation, plus the normal behavior of waves, namely interference.

VII Energy and the nonlocal collapse of photon waves

Most explanations of the photon treat it as a unitary object which makes the dualism contradiction unavoidable. Positing unitary excitation objects that combine both is without any physical grounding.

The approach taken here is to recognize that while single, the photon has two identities. Photon waves constitute one identity. They are dependent upon kinetic energy, yet separate from it; they enable objective probability while (cleverly) avoiding detection by our instruments. It is time to look at the photon's other identity, oscillatory kinetic energy.

Photon kinetic energy, a scalar, has no position operator; it is not accessible to us in the dimension where we expect it, space (I.a). The waves this energy sustains also collapse. We know they travel all available paths – perhaps intergalactic – until reception. Yet at photon reception these extended and rarefied waves disappear and do so nonlocally. Again, this is basic physics.

Since photon waves are immaterial and dependent upon something else, one might assume that collapse characterizes anything with those two attributes. For example, the gravitational field (or gravitational spacetime distortion) is also immaterial, potential and dependent upon a sustaining rest mass. And if that mass ceases to exist, then gravitational effects – spread across space – collapse. The problem is, of course, that this collapse cannot be instantaneous without violating the speed of light limitation. The sustaining object (the source), and the potential dependency it sustains (the effect), cannot both operate in space and still support nonlocal collapse. That is the final clue we need. Sustaining object and its potential dependency must be orthogonal to each other.

We receive photon kinetic energy as an event (reception) mediated by the space-advancing dependency it creates, waveform momentum. The latter can collapse nonlocally only if the entire

waveform is: 1) immaterial and potential; and 2) a dependency with a single point of failure in an orthogonal dimension, namely time.

a. As pure oscillation cycles, photon kinetic energy resides/oscillates in the time dimension. Its only presence in orthogonal space is as a dependent, latent, waveform identity, i.e., photon momentum and EM cycles.

Putting photon kinetic energy in time – denying it a space presence – explains why this energy: 1) is unaffected by diffraction in space; 2) can only project a collapsible, waveform latency in orthogonal space; and 3) can only interact with space-residing rest mass via a discrete event (reception) that mass and energy share.

b. The photon having two distinct identities – one an entity, one a latency – functioning in opposite dimensions finally provides a physical explanation for how something single can be dualistic.

Dualism rests upon two fundamental attributes of physical reality: photon momentum being a projected dependency, and space and time being orthogonal.

Our view of physical nature is biassed in favor of vision and space; to counter that, symmetry and the equalities of special relativity should be our preferred physics guides. Consider the symmetry-equality that characterizes mass versus energy; specifically, rest mass without kinetic energy and kinetic energy without rest mass (the photon).

The inertial rest mass particle occupies and requires an interval (volume) in one dimension, space, where it is stationary. The photon's energy oscillation cycle occupies and requires an interval in another dimension, time, where it is stationary (infinite time dilation). Each advances at the maximum rate in the non-stationary dimension, the inertial particle over time, the photon over space.

Of course, such symmetries and orthogonal dimensions are not for everyone and those (many) who can't accept photon momentum as objective probability will like photon energy in time even less.

But there is a lot of indirect evidence that photon momentum is latent/potential; perhaps even stronger evidence for electron momentum, see Sec. IX. The best and most compelling evidence – assuming you are open minded – for kinetic energy residing in time is entanglement, see Appendix, A.4. While it is difficult for us to imagine time as a host for anything real, we happily have space as a host for almost everything: fields galore, mathematical abstractions, strings, higher dimensions and many, many worlds.

Lagrangian-Hamiltonian mechanics – how objects move in space over time – is the description of objects advancing in two dimensions; it does not apply to objects stationary in one dimension. We don't apply mechanics to the space-stationary particle, but we are convinced that mechanics applies to the time-stationary photon.

c. Lagrangian-Hamiltonian mechanics – any mechanics – doesn't apply to entities stationary in one dimension, neither the chair you are sitting in, nor the photon.

VIII Photon space travel

Stationary objects may undergo a change of state when advancing in their non-stationary dimension. Probabilistic change of state (reception) occurs for a photon stationary in time and advancing in space. Probabilistic change of state (decay) occurs for an inertial carbon-14 atom stationary in space and advancing in time.

The carbon-14 atom's rest mass doesn't navigate time to reach a decay point; it is simply oblivious (orthogonal) to time but remains always available for a time-located change event.

So it is with a solar photon's kinetic energy being orthogonal to its possible target, the earth. This quantized energy does not space travel from sun to earth; only its potential-probabilistic momentum (and EM oscillations) so travel at the speed of light. Once this photon's rarified latency/wavefront reaches the earth it may, or may not, occasion the reception event featuring undiminished, quantized kinetic energy (as momentum change). Only a latency – potential momentum as objective reception likelihood – travels all available space paths, only some few of which intersect the earth, and fewer of those actually initiate a reception event.

Time-residing photon kinetic energy and a space-residing rest mass target can only meet as a quantized (reception) *event* discretely located in both dimensions. This is the subtlety, the genius, of space and time being truly orthogonal.[6]

Wave optics clearly tells us that probabilistic, immaterial photon waves travel all available paths in space and collapse at a reception point. But quantum physicists generally ignore wave optics. To his credit, Richard Feynman doesn't ignore available paths. He argues [7, Chap. 2] that all possible photon paths sum to a final, most probable, path (of least time) between emission and reception points. But he assumes that it is photon-as-particle following these paths and concludes, wrongly, that "Nature has got it cooked up so we'll never be able to figure out how She does it… [p. 81]."

The quantum pioneers had no inkling of momentum's potential, waveform and probabilistic nature. So, when de Broglie waves were confirmed, and when Schrödinger introduced his wave mechanics, the quantum pioneers had no explanation to offer. They settled on adding yet another paradoxical feature to QM, namely matter can be both wave and particle; this to go along with the unexplained constant speed of light, wave function collapse and photon duality. All, not surprisingly, related to a misunderstanding of momentum.

Any object with kinetic energy – massive or massless – has potential, waveform momentum as a dependency. It is large rest mass that obscures all of this. But a particle as tiny as the electron allows momentum to display its full features and to that we may now turn.

IX The electron and the momentum wave packet

Photon kinetic energy has its potential momentum waves advancing as a latency wavefront of weighted possibilities; it controls the likelihood of photon reception on space paths (Sec. II, IV).

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[6] Photon reception is an event combining a discrete space location with a discrete time location. Graphing events, as Minkowski did, has space and time axes of an event as orthogonal (perpendicular). It is when you take two events – or a single event measured by different observers – and calculate a space plus time interval between them that space and time get mashed together into a mathematical "spacetime." Mathematical physics (e.g., the Dirac equation) requires this spacetime. But any measurement (or collapse) becomes an event located in familiar, orthogonal space and time. Of course, mathematicians (Minkowski, Einstein, Dirac) grant spacetime its own reality.

An electron's kinetic energy has its potential momentum as multi-frequency waves with these (de Broglie) waves constructively interfering to create a wave packet accompanying the electron's rest mass.

a. An electron's kinetic/particle identity (rest mass) advances in space and is accompanied there by a potential/waveform identity, a momentum wave packet. Potential waveform momentum is the space expression of the electron's time-residing kinetic energy.

The electron is truly dualistic in space: familiar, discrete particle rest mass accompanied by a non-discrete, immaterial, potential momentum waveform. In contrast, the photon is not dualistic; it is all wave in space and no particle is involved; we mistakenly regard photon reception as particle impact when it is actually a quantized energy transfer event between orthogonal dimensions.

b. The electron's packetized potential momentum waves comprise a spread of latent vectors, and hence of path-location possibilities, that are objectively possible, but only realized randomly and acausally.

If one could progressively reduce the electron's rest mass, then the momentum wave packet would come to resemble the waves of the photon and have no defined location but exactly defined wavelength, and hence exact momentum.

c. The presence of a waveform of momentum-path latency accompanying a low mass particle in space is the physical explanation for why probability dominates the microworld. By overlooking potential identities – by retaining traditional momentum – QM and QFT regard probability as an unexpected "feature" that complicates their mechanics.[7]

d. **Electrons live in a "fuzzy" world where the discrete and the continuous are joined and in tension: 1) location depends upon electron rest mass whereas momentum depends upon electron kinetic energy making them non-commuting; and 2) what is material, discrete and not latent (i.e., rest mass) gets blended with what is immaterial, wave-continuous and latent (i.e., potential momentum).**

If the electron is in an orbit, its momentum waves must realize whole cycles creating a standing wave that the wave function can model. The wave function models wave intensity over space and momentum wave intensity correlates with latent possibilities and ultimately with probable location.

A standing wave also characterizes the potential momentum of an alpha particle trapped within the potential well of a heavy atom. This wave's wave function shows a very small portion outside the atom's potential well. This represents a measurable likelihood that the particle may escape confinement (tunnelling) leading to the heavy atom's probabilistic decay. Steady-state (standing) waves of potential momentum allow us to predict particle location (and hence decay), but only for the aggregate.

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[7] Heisenberg's uncertainty principle ($\Delta x \cdot \Delta p \geq {}^{h}/_{4\pi}$) is now a verity obviating a search for a physical cause for probability. Same with Einstein's second postulate for the constant speed of light. Generalized principles passed down to generations become a substitute for physical explanations. Heisenberg's uncertainty principle is extremely useful for justifying virtual particles; his theory of potentia – perhaps more important – is ignored.

e. Potential momentum is responsible for wave behavior, plus all probabilistic processes within the microworld: decay, orbital paths, photon emission, photon absorption, etc.

All moving particles generate potential momentum waves whatever their size. But as particle rest mass increases, so does wave constructive interference creating a tight, spatially-defined packet with minimal to no wave character. The momentum packet then becomes what classical physics expects: a quantity with a well-defined vector minus any probabilistic effects. Momentum still remains potential as the dependency of kinetic energy, but its ability to diffract disappears and its range of likely paths has narrowed to one.

Since the wave nature of momentum for large moving objects is undetectable to us, we *imagine* the object has a quantity of what we call kinetic energy that creates momentum change upon release (impact); we then assume the same for the electron and for massless radiation. Initial assumptions – e.g., kinetic energy as quantity; or this quantity needing a carrier; or photon point reception equaling particle impact; etc. – can seem so reasonable as theory and yet be so wrong.

Erwin Schrödinger's wave equation (1927) featured calculations of electron kinetic and potential energies using, appropriately, a momentum operator ($-ih\frac{\partial}{\partial x}$). Although a great success in predicting electron energy levels, it became apparent that (complex-valued) solutions only yielded a probability density for electron location. An equation describing the state of a particle that only yielded weighted probabilities called for some creative thinking; or rather some borrowing from wave behavior; enter superposition of quantum states.

The concept of superposition of pre-existing states, each ready to emerge for quantum objects is pure invention; worse, it is a one-off explanation now embraced without reflection. It gives quasi-reality to hidden states; it's a poor man's latency without a physical basis. The word itself is a bit pretentious. Tied to particle/object states, it has no way in our familiar world for explaining rarefication or for distinguishing gradations of probability. In contrast, photon and electron potential momentum waves – and EM waves –vary in intensity and hence in weighted possibilities in familiar 3-D space over time.

Superposition of states as a facile analogy to superposition of waves raised a problem not all seemed to notice. States are discrete, waves are continuous. Merging the latter yields a new continuous wave or wave-packet. It is not clear how discrete items – objects, states or locations – can be superposed.

X The measurement problem and Schrödinger's cat

The apparent lack of defined position or momentum for an electron, plus the discontinuity of measurement (of momentum transfer) led to what became known as the "measurement problem [8]." Can a superposed particle be in two places or two states at the same time? Does the wave function represent reality or only our imperfect knowledge of reality?[8] Do sub-atomic particles even have a real state or do we impose a state on them by our choice of measurement?

[8] Because no one knows what the wave function represents, it can be applied to anything: the vacuum, the universe or a cat.

If quantum superposition is a real state of states, can this superposed, composite state – possibly including incompatible features – be passed down a causal chain much like the state of a light switch, either on or off, determines the state of a connected light bulb?

That was the question Schrödinger posed, tongue in cheek, in 1935 in his famous thought experiment [9] of a cat whose fate depended upon the state of an alpha particle insecurely bound to the nucleus of a heavy atom. The wave function for the alpha particle showed it both nucleus-bound (cat alive) and nucleus-unbound (cat dead). The problem with the superposition of states was transferred from mathematics and theory to a living being we could see and touch.

A correct analysis of the cat problem flounders on two mistakes. First, is to overlook the potential/latent nature of the electron's momentum and deny this momentum a presence in space. Second, is to assume that the wave function applies to the alpha particle's rest mass, or to our knowledge of it. No one thinks of the wave function (the equation) as describing a latency: waveform momentum whose varying intensity corresponds not to particle positions, but to the likelihood of (potential for) particle positions.

Alpha particle position likelihood translates into probable particle states, bound, unbound. Being located in space as a wave packet, momentum is part of the causal chain; but being latent it only projects probabilities down that chain via possible particle location. The cat is at risk of death from poison, but only the jeopardy of this, not the state, extends down the chain from the alpha particle.

No definitive solution to the issue Schrödinger posed has emerged since particle physics has no place for latent identities projecting objective probabilities within a causal chain. Einstein and Schrödinger are correct; QM is not the full story. It is not because it excludes: 1) latent identities; 2) kinetic energy as an entity present in a dimension; and 3) orthogonal space and time. Remedying these defects is to restore realism in physics, just not the realism of classical physics.[9]

XI No new physics

Preceding sections have presented kinetic energy and momentum as constituting a dynamic bond; a bond that spans two dimensions and two states: residing entity, advancing latency. Kinetic energy is an entity hosted in a dimension while momentum is its space-advancing agent that effects work events.

In contrast, current theory – QM, QFT, the Standard Model – retains the classical physics concepts of kinetic energy and momentum as separate, but related ($E = p^2/2m$) quantities requiring a particle or excitation for advancement in space.

These two views of kinetic energy and momentum clearly differ. Which one is correct makes no difference in terms of computation; only quantitative values count in an equation. The QM/QFT view isn't going anywhere; it allows one to formulate equations and make predictions as physics has always done. It is very successful.

It is the dynamic bond view that provides a physical explanation for wave behavior and probability. It also – as noted in Sec. VII – deepens our understanding of the symmetry between the opposites of special relativity, namely space-time and the mass-energy.

[9] Realism in the broader sense – a reality independent of observation; plus, our ability to understand why things are as they are – is still valid. But, unfortunately for Einstein, indeterminism (no causal relation), randomness for individual events, and latency are part of that reality.

The dynamic bond view of kinetic energy and momentum is grounded on things physical; it is physics, not metaphysics. Nor does it constitute a new physics; it offers no new equations or predictions. It complements current, computational physics; and it goes further than the quantum pioneers could in getting rid of classical assumptions at the foundational level.

Physics is more than beautiful equations and computing the finer details of atomic spectra. True scientists are in awe of the subtleties and symmetries that Nature provides; they want – actually need – to understand why things are as they are. Experimenting on something (e.g., the double slit, nonlocality) without understanding what takes place is like the blind person describing the elephant by touch; it is not science. Those who never question the ad hoc postulates they have been taught and who use equations without understanding what they represent have become technicians. It is a bit embarrassing that QM and QFT feature the wave function as foundational, yet cannot tell us what the equation represents. A broader physics can so inform us; it is just not the physics of Lagrangian-Hamiltonian mechanics.

That said, physicists must earn a living and they are now subject to many professional and bureaucratic obligations. Most lack the time or the inclination to investigate features of QM that others term "paradoxes." So be it; there is room for both approaches to Nature. But there are instances – and not just a few – where both computation and experimentation benefit from a better understanding of foundational issues.[10]

XII Summary

For radiation: 1) there is no rest mass to justify invoking particle physics; and 2) space-advancing photon momentum has the waveform as an expression of oscillatory kinetic energy, $p = E/c = hf/c$. Photon waves are momentum waves; they are immaterial and probabilistic as wave optics demonstrates. They advance on their own in space at the speed of light; they constitute a wavefront of possible reception.

Dependent upon – an expression of – photon energy, photon momentum waves spread out and rarefy in space, but collapse to deliver their momentum at a point on a target thereby doing work that we call energy (and mimicking particle impact). A dependency of kinetic energy that is immaterial, probabilistic, advances on its own, expands/rarefies and finally collapses to deliver work (our energy) is an objective (i.e., space-present) *potentiality*. Photon momentum is a latency advancing as a wavefront; latency explains why the photon and the microworld are probabilistic and why collapse occurs, two phenomena current physics cannot explain.

For an atomic electron, a standing wave of potential momentum forms with nodes of greater intensity having a greater probability of electron location. This is what the wave function models, a space-located, immaterial, collapsible latency. When particle rest mass gets large, the wave packet condenses, momentum wave vectors converge, wave behavior and latency is lost, and the particle behaves as classical physics predicts. Only for the photon and for the microworld can we see that:

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[10] For cosmology, might the (not visible) potential momentum of unterminated stellar photons be related to dark matter or dark energy? Might "gravity waves" actually be potential momentum waves in 3-D space? Can momentum waves explain some things now attributed to the ubiquitous virtual particle? What about spontaneous emission? Currently, an atom's electron is presumed to be in a stationary, time independent state (energy eigenstate); but electron momentum embodying potential (and acausal) change seems to challenge that. Could those thousands of nonlocality experiments done each year benefit from a real understanding of the photon? And finally, a resolution of the paradoxes of QM would be a welcome antidote to the prevailing portrayal of QM as: 1) mind-bending; 2) beyond our reason; and 3) proof that realism is dead and that Einstein was wrong about QM and nonlocality.

a. Momentum is an immaterial, space-advancing, waveform dependency of (oscillatory) kinetic energy (an entity). Being latent, it has the potential, and the capacity, to initiate energy-transfer work events. It traces out space paths either of objective reception likelihood (the photon) or of objective particle location likelihood (the electron).

A recognition of momentum's latency resolves much more than just what the Schrödinger equation is modeling. It addresses all the major paradoxes of radiation and QM. Eliminating a carrier object (particle) for radiation means that the photon in the double slit simply undergoes diffraction of its reception-possibility wavefront, see Appendix A.1. It means that the constant speed of light is simply the phase velocity of immaterial waves, see A.2. And it means that nonlocality doesn't involve signaling between space-separated photon "particles," see A.4.

It is a strange time for physics. The role of institutional physics – universities, research funders, research labs – is now dominant. Its participants, generally speaking, take pride in the progress made in QM and are convinced that 100 years of effort has brought us close to understanding how Nature operates. But QM remains perplexing for the educated public and they sense – like Einstein – that perhaps it is incomplete; they seek clarification. The result is a proliferation of non-specialist publications – books, articles (scholarly and popular), videos, podcasts, etc. – dealing with QM and with the founders, the experiments, the evidence and the meaning of this new physics.

We do not lack for theories explaining QM. But these theories invariably focus on a specific issue – usually the wave function and its collapse (e.g., Hugh Everett) – and their resulting explanation is both ad hoc and issue specific. As Feynman reminded us long ago, solving dualism is the key to solving everything else, even, it turns out, seemingly unrelated puzzles like probability and wave function collapse. And the barrier to resolving dualism has been our holding on to some fundamental assumptions of classical mechanics, namely: 1) physical reality – including radiation – consisting of existing objects in space; and 2) momentum and kinetic energy being quantities carried by objects within that space.

The true revolution in modern physics was not Planck's discovery. The true revolution was the transition of physics to the microworld and to radiation just before and after 1900. By retaining so many classical concepts we are still working our way through that transition. One hundred years and counting for a transition is not that extended in the long history of physics. But, like every generation, we think we have an almost finished product and inevitably we focus on the wrong things to "finish up."

Coda:

- **Momentum as a waveform latency is the *physical* explanation for why both the photon and the electron are probabilistic and behave as waves.**
- **An electron's position and momentum do not commute because the former depends upon material, space-located, rest mass and the latter upon kinetic energy's immaterial, space-continuous latency.**
- **Photons are emitted by an atomic electron; a particle may tunnel through a potential barrier; both are random, acausal realizations of momentum latency possibilities.**

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Appendix A

Radiation Paradoxes

The radiation paradoxes treated below – the double slit, the constant speed of light, delayed choice in the Mach-Zehnder interferometer and nonlocality – have been around for a long time. They are intractable when treating radiation as particle mechanics hence virtually all physicists avoid them.[11] So it is that the lesson they teach us – that our physics of radiation is quite wrong – is lost.

A.1 The double slit

There is no photon "particle" traversing a double slit. The photon in space consists of immaterial, collapsible, latent/potential waves tracing out paths of reception likelihood. Waves of an individual photon pass through both slits causing interference between the two paths. Placing a detector behind one slit blocks those waves thereby preventing interference with waves of the other slit. On a random basis, the blocked photon waves, being latent and without mass or energy, either collapse without a trace, or they initiate point reception on the detector, thereby collapsing waves on both slits. In the former (no reception) case, the remaining, un-collapsed waves progress through the unblocked slit and trigger reception at a random point on a reception screen.

Because blocking one slit eliminates two-slit interference, commentators typically conclude that blocking one slit makes the photon a particle and not a wave. Photon reception is not particle impact; a time-residing photon energy quantum only intersects a space-residing target at a point. See A.3 below.

A.2 The speed of light

Between emission and absorption events, the only *space* presence a photon has are unhosted, immaterial waves: EM waves and potential momentum waves sharing the same frequency. Without a hosting medium, these waves have a phase velocity of wavelength times frequency.

If an observer moves toward the wave source the wavelength contracts but the frequency increases. If the observer moves away from the source the wavelength expands but the frequency decreases. The phase velocity (our "speed of light") stays the same regardless of observer movement.

All phenomena have a physical explanation. The ad hoc, second postulate of Einstein – the speed of light as constant – is both unphysical and entirely unnecessary once radiation is freed from particle mechanics and the concept of kinetic energy as carried by a particle, or a field ripple, navigating space is dropped.[12]

A.3 The Mach-Zehnder interferometer

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[11] In the summer of 2000, some eminent physicists drew up a list of ten items for 21st century physics to resolve [10]. None of the paradoxes listed here made the list; not even nonlocality, nor what the wave function represents.

[12] Alas, nobody cares about the constant speed of light. All now assume that it is simply a "feature." The Doppler effect is a big clue that the constant velocity of light is really a phase velocity.

The MZI illustrates the case where photon potential momentum waves may be optically split with one portion collapsing without a trace and without triggering photon reception. Of course, something immaterial, objective yet latent, that by itself cannot register on our instruments, gets misinterpreted.

The waves of a single photon pass through the first beam splitter of the MZI. These immaterial, possibility-of-reception waves split at half intensity on the two MZI paths. In the case of no path blockage, these two potential momentum waves meet at the second beam splitter where their interference confirms the wave nature of the photon.

But assume one MZI path is blocked and that the blocked potential momentum waves on this path do not trigger reception despite their 50% probability of doing so. These waves collapse without registering as an event since they have no kinetic energy and their momentum is only potential. Photon waves on the other path now convert to 100% reception probability and continue through the second beam splitter with no interference.

Two erroneous conclusions generally follow from this: 1) the collapse without a trace of photon waves on the blocked path means that "the photon" took the other path; and 2) blocking or unblocking a path can change the photon from particle (one path or the other) to wave (two paths intersecting).

John Archibald Wheeler embraced these erroneous conclusions and compounded them a bit [11]. He reasoned that: 1) the photon made a wave versus particle "choice" at the first beam splitter; 2) blocking one MZI path forced the photon to be a particle (i.e., be received at a point on one path or the other without interference); and 3) if the photon's choice at the first beam splitter was a wave, and if a path was blocked after that choice, then the original (beam splitter) choice could be changed retroactively to a particle. He more than hinted/teased at the notion of retrocausality without actually affirming it. Instead, he adopted the position of his mentor, Niels Bohr, and argued that the photon's nature is determined by how we decide to measure it,[13] either blocked or unblocked. The assumption that the photon is unitary, plus failing to recognize photon waves as objective possibility leads smart people into silly conclusions.

A.4 Nonlocality

Entities can only reside (occupy an interval) in one dimension, rest mass in space, oscillatory kinetic energy cycles in time. Two similar entities may bond together in their shared dimension to create a unified whole such that to change one is to change the whole. A chloride ion may bond with a sodium ion to create salt which will then advance (persist) over time. With this bond in space, a change event affecting one ion affects both ions and does not require communication over the advancing dimension, time.

It is the same with photons bonding their energies in the time dimension where they reside, while their potential identities advance separately in space. Any change affecting both photon energies – such as spin (anti) correlation – does not require communication over the advancing dimension, space.

High energy photons traversing a nonlinear crystal occasionally split yielding two daughter photons whose energies are then adjacent and entangled in time. The spin of the bonded pair is undefined

[13] This view of a "reality" as observer-determined dismayed Einstein who wrote, "…the sore point lies less in the renunciation of causality than in the renunciation of a reality thought of as independent of observation [12, p.374]."

(can't be measured). Each photon has its own potential momentum wavefront that traverses free space or a fiber optics cable.

When a potential momentum wavefront for one photon initiates reception, the kinetic energy for that photon must leave the bond in the time dimension to become a work event in two dimensions. In doing so the spin of both photons is defined (anti-correlated). Hence spin determination takes place in the time dimension and coordination is instantaneous as a wholistic change. Photon spin coordination is between adjacent, time-residing, occurring entities; coordination is not transmitted over space; there is no nonlocal signaling.

Einstein argued that nonlocality is a prime indication that QM is incomplete or somehow defective. He was correct in that QM's interpretation of radiation as mechanics is a defect. As for his disputing nonlocality, currently every pop science writer (and a few physicists) chide him for his "great mistake." It turns out that Einstein the realist was right there as well. With spin coordination in time, there is no "spooky action at a distance."

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Abbreviations:

EM	electromagnetic
QM	quantum mechanics
QFT	quantum field theory
MZI	Mach-Zehnder interferometer

References

[1] Richard Feynman, *The Feynman Lectures on Physics*, https://www.feynmanlectures.caltech.edu/I_04.html (1964-6)
[2] D. Ellerman, *How to Understand Quantum Mechanics: The case for the literal interpretation in terms of objective indefiniteness*, https://papers.ssrn.com/sol3/papers.cfm?abstract_id=5037601 (Nov. 2024)
[3] J. van Dongen, *The interpretation of the Einstein-Rupp experiments and their influence on the history of quantum mechanics*, https://arxiv.org/pdf/0709.3226
[4] A. Shimony, *The Reality of the Quantum World*, Scientific American. v.258 n1 (Jan. 1988)
[5] Frank Rioux, *Polarized Light and Quantum Mechanics*, https://faculty.csbsju.edu/frioux/polarize/POLAR-sup.pdf
[6] P.A.M. Dirac, *The Principles of Quantum Mechanics*, Oxford University Press (1930)
[7] Richard Feynman, *QED: the strange theory of light and matter*. Princeton Univ. Press (1985)
[8] M. Genovese, *Interpretations of Quantum Mechanics and Measurement Problem*, Advanced Science Letters, Volume 3, Number 3, September 2010, pp. 249-258(10) DOI**:** 10.1166/asl.2010.1133
[9] E. Schrödinger, *Die gegenwärtige Situation in der Quantenmechanik* (The present situation in quantum mechanics), Naturwissenschaften. 23 (48): 807–812 (November 1935)

[10] *Physics Problems for the Next Millennium* https://www.preskill.caltech.edu/millennium.html (2000)
[11] J. A. Wheeler, *The 'past' and the 'delayed-choice' double-slit experiment*, Mathematical Foundations of Quantum Theory. Marlow, A.R. (ed): Academic Press, New York, 9–48 (1978)
[12] J. Stachel, *Einstein and the quantum: Fifty years of struggle*, R. G. Colodny (ed.): *From quarks to quasars*, Univ. Pittsburgh Press, Pittsburgh (1986)